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Abstract- A diagnostic approach based on multi-scale integrated analysis and model simulations was employed to identify specific or common biophysical constraints, technological changes and ecological compatibilities of the diverse subsistence (SUB) and organic (ORG) agro-ecosystems in the Fertile Crescent (FC) of West Asia and the organic and conventional (CNV) agro-ecosystem in the Northern Corn Belt (NCB) and Northern Great Plains (NGP) of the U.S. For each agro-ecosystem, soil carbon, total yield, temporal yield variance and yield coefficient of variation per crop rotation were used as sustainability indicators. Thresholds of technologies necessary for the proper functioning and flow of agro-ecosystem services were identified under the most-likely IPCC-projected climate change scenarios for the next 30 years. The carbon budgets of agro-ecosystems were largely related to the choice of crops, crop sequence, and length of the crop rotation, and were influenced by external inputs, tillage system and removal of crop residues. Carbon depletion is expected to be less in organic and subsistence agro-ecosystems when nitrogen-fixing legumes are included in more diverse crop rotations and when crop residues are incorporated into the soil. Potential nutrients loss to the environment was significantly larger in conventional systems, and nutrients are expected to be depleted over time in subsistence- faster than in organically-managed soils. Optimal and sustainable agricultural intensification is feasible through agro-ecosystem diversification and the proper integration of genetic and natural resources management. In all agro-ecosystems, for more diverse rotations to be adopted at a large scale, there needs to be large and easily accessible markets for the additional products.

Key Words: Models, agro-ecosystem services, sustainability, Fertile Crescent, Corn Belt

Résumé- Contraintes biophysiques et des compatibilités écologique des agro-écosystèmes diversifiés. Une approche de diagnostic basée sur la multi-scale analyse intégrée et simulations du modèle a été employé pour identifier particulière ou commune contraintes biophysiques, les changements technologiques et les compatibilités écologique de la subsistance diversifiés et les agro-écosystèmes biologiques dans le Croissant Fertile de l'Asie Occidentale et de l'agro biologiques et conventionnelles écosystèmes dans le Corn Belt et du Nord des Grandes Plaines des États-Unis. Pour chacun des agro-écosystèmes, le carbone des sols, le rendement total, la variance du rendement temporel et le rendement coefficient de variation par la rotation des cultures ont été utilisés comme indicateurs de durabilité. Seuils de technologies nécessaires au bon fonctionnement et le flux des services des agro-écosystèmes ont été identifiés sous la plus probable GIEC aux prévisions des scénarios de changement climatique pour les 30 prochaines années. Les budgets de carbone des agro-écosystèmes sont largement liés au choix des cultures, la séquence des cultures, et la durée de la rotation des cultures, et ont été influencés par des éléments extérieurs, le système de travail du sol et l'enlèvement des résidus de récolte. Appauvrissement de la couche de carbone devrait être moindre dans les écosystèmes agricoles organiques et de subsistance lorsqu'ils azote des légumineuses de fixation sont inclus dans les rotations de cultures plus diversifiées et lorsque les résidus de culture sont incorporés dans le sol. Potentiel de perte de nutriments dans l'environnement a été significativement plus importante dans les systèmes conventionnels, et les éléments nutritifs devraient être épuisées dans le temps de subsistance plus vite que dans les sols organiques gérés. Optimale et d'intensification agricole durable est possible grâce à la diversification des agro-écosystèmes et la bonne intégration de la gestion des ressources génétiques et naturelles. Dans tous les agro-écosystèmes pour les rotations, plus diversifié qui sera adopté à une large échelle, il faut avoir des marchés vastes et facilement accessibles pour les produits supplémentaires.

Mots clés: Modèles, services des écosystèmes agricoles, la durabilité, le Croissant Fertile, Corn Belt

INTRODUCTION

The diversity and intensity of agro-ecosystems (AESs) in developing (Kassam et al., 2009) and developed (Izaurralde et al, 2003) countries have been changing over time in response to a number of interacting biophysical and social factors at the local, regional, and global levels. The impact of increased spatio-temporal climate variability on AESs is likely to be intensified by climate change, which will disrupt many ecosystem functions, altering their capacity to provide goods and services and rendering them more susceptible to degradation (ICCP, 2007; Friend, 2010). In addition, the security of food supply to an increasing world population has turned into a pressing issue worldwide (Friend, 2010). Therefore, quantifying biophysical constraints to productivity and sustainability, and identifying ecological compatibilities of diverse AESs will help determine the management options that are technically, agronomically, and economically viable in the face of predicted climate change and increasing population pressure (Desjardins et al., 2007). Nevertheless, agriculture in these AESs is challenged more than ever to achieve greater efficiency in resource use while providing high-quality food, a wide range of ecosystem services, protecting the environment, and sustaining rural economies and societies (Grace et al., 2006).

Recently, agricultural intensification, especially of cash crops and mixed farming, has taken place only in the high-rainfall (>500 mm yr^{-1}) parts of the FC (Thomas, 2008), or under irrigation in the drier parts (Hole, 2008). A step-wise strategy of using external inputs, without immediate and expensive financial outlays, is proposed for agricultural intensification of agro-ecosystems in the drier rain-fed (<350 mm yr^{-1}) areas, which are vulnerable to recurrent droughts (Ludwig and Asseng, 2006; Hole, 2008). On the other hand, the industrial CNVs in the U.S. have promoted the simplification of AESs, with reductions in the number and variability within crop species (Izaurralde et al., 2003; Kustermann et al., 2007). Increased specialization of CNVs at the field, farm, and landscape levels produced monocultures that potentially increase environmental risks because they reduce biodiversity, ecosystem functions and ecological resilience, and they may be highly vulnerable to climate change (Rozenzweig and Tubiello, 2007).

Sustainability of AESs cannot be understood using any single dimension or criterion (Belcher et al., 2004), and the feedback between crop production and each of crop rotation, soil characteristics, and several management practices is an important driver of AES sustainability (Hobbs et al., 2008).The biophysical characteristics of any AES are critical determinants of its overall performance and sustainability (Belcher et al., 2004). Therefore, a key challenge is to improve the understanding of complex biophysical processes and environmental consequences of AES intensification of SUBs, productivity optimization of ORGs, and diversification of CNVs so that they can be managed and enhanced to ensure sustained food production and provision of ecosystem services (Sandhu et al., 2007).

The need is urgent to identify appropriate adaptation and mitigation strategies of AESs, increase their resilience to current and projected environmental and population pressures, and optimize their overall performance (Lal, 2008). Modeling of AESs enables the transformation of climate variation into variability of cropping systems' performance (Wang et al., 2009), and allows the assessment of anthropogenic interventions through scenario analysis (Keating et al., 2003). The objective of this study was to develop a diagnostic approach based on multi-scale integrated analysis and model simulations to identify specific or common biophysical constraints, technological changes and ecological compatibilities of representative subsistence and organic AESs in the FC of West Asia and the organic and conventional AESs in the NCB and NGP of the US.

1. MATERIALS AND METHODS

The SUB and ORG AESs in the FC of West Asia and the ORG and the recently- developed, more sophisticated CNV AESs in the NCB and the adjacent NGP of the US were represented in this study. Empirical data collected from conventional and diversified short- and long-term field experiments in three contrasting AESs were used to parameterize the Agricultural Production Systems Simulator (APSIM) model (Keating et al., 2003). This model is capable of simulating biophysical processes in crop growth and farming systems and was employed to conduct 30-year simulation runs using crops, soils, management practices and weather data for a representative location in the FC (32° 36´ N, 35° 54´ E) and the US (45° 41´ N, 95° 48´ W). The following scenarios were developed for each location: (1) Baseline (B), using current temperature, CO_2 concentration ([CO_2]), and rainfall for each AES, (2) S1 as the most likely IPCC scenario for 2030 with 2.0 °C above baseline, Rainfall+10% for CB and -10% for FC, and without CO_2 fertilization (380 ppm), and (3) S2, which differs from S1 in [CO_2] fertilization (560 ppm) (IPCC, 2007).

For each AES, we assessed the impact of conventional and alternative crop rotations, tillage, nutrients (nitrogen and phosphorus), crop residue management, temperature, and rainfall on soil carbon budget, TY, TV and CV (Table 1). A normalization procedure was used to allow for direct comparisons between yields of different rotations and between different AESs, then total temporal variance was partitioned into its components and the cumulative expected probabilities were calculated for baseline and simulated TY, TV, and CV. A database on simulated yields was used to calculate the cumulative probability of not exceeding a critical yield threshold (CYT) for each crop rotation.

Table 1. Management options used or simulated in the study in conjunction with baseline and most-likely climate change scenario for each agro-ecosystem (tillage: MB=mouldboard, MT=minimum tillage, ST=strip tillage).

Location	Management combinations					
	Agro-ecosystem	Crop rotation	Tillage	N,P fertilizers	Weed control	Crop residue incorporated
West Asia (FC)	SUB	2-yr*§	MB	No	None	No
(~350 mm rainfall)	SUB	3-yr	MT	Yes	Chemical	Yes
	ORG	3-yr	MB	No	Mechanical	Yes
USA (NCB, NGP)	CNV	2-yr	MB	Yes	Chemical	Yes/No
(~780 mm rainfall)	CNV	4-yr	ST	Yes	Chemical	Yes/No
	ORG	2-yr	MB	Yes	Mechanical	Yes
	ORG	4-yr	ST	Yes	Mechanical	Yes

**§ : FC: 2-yr-SUB (wheat-fallow) 3-yr-SUB & ORG (wheat-food legume-fallow); USA: 2-yr-CNV & ORG (corn-soybean), and 4-yr-CNV & ORG (corn-soybean-wheat-forage legume).*

Conditional probabilities of not exceeding CYT under B, S1 and S2 scenarios were calculated according to Luo et al. (2007). Location- and crop-specific CYT were estimated based on current and modelled net primary productivity (i.e., the annual increment in plant above-ground dry matter after allowing for losses due to respiration of CO_2; NPP in Mg ha^{-2} yr^{-1}) according to Friend (2010), then grain yield was estimated using a crop-specific harvest index (Heng et al., 2007; Cayci et al., 2009). In addition, the normalized risk indices (0=small to 1=large) of biophysical constraints under baseline and climate change scenarios were estimated in different location/agro-ecosystem/management combinations according to Li et al. (2009) and Castoldi and Bechini (2010). Agro-ecosystems were declared as non-sustainable if the conditional probability of not exceeding CYT was ≥50. Finally, alternative strategies for sustainable intensification of agricultural production in the fragile SUB and

ORG of the FC and for systems optimization and diversification in the NCB and NGP of the US are discussed.

2. RESULTS

The SUB and ORG AESs that have emerged in the FC of West Asia over centuries of biological evolution, and the organic and the recently-developed, more sophisticated CNV AESs in the NCB and the NGP of the US represent contrasting rain-fed production systems. Current SUBs in the FC lack technological change, rely on low external inputs, and are increasingly marginalized. The CNVs in the NCB and NGP of the U.S. mostly focus on a single ecosystem service, over-consume environmental resources and release chemicals to the environment; whereas, ORGs focus on multiple ecosystem services, consume less environmental resources and retain more nutrients as compared to CNVs. Multivariate statistical analyses of baseline and simulation data indicated that future AESs have to function within constraints imposed by climate change and the availability of increasingly limiting external inputs, especially in the FC.

2.1. Baseline and simulated scenarios

Baseline and simulated average rotation yields (Table 2) reflect significant differences between and within SUBs, ORGs and CNVs as a result of management options and biophysical constraints imposed by the simulation scenarios. Average simulated rotation yield of CNVs will not be always significantly larger than those of ORGs, especially under drought conditions; however, both are expected to have significantly larger yields than SUBs, even if germplasm responsive to external inputs was used in the latter. Improved management and a diverse crop rotation may result in small relative yield increases in the FC; whereas larger relative yield increases are expected in CNVs, but not ORGs in the U.S.

Table 2. Average baseline and simulated rotation yield, temporal yield variance, coefficient of variation and conditional probability of yield not exceeding CYT under baseline (B) and two climate change scenarios (S1 and S2) of different agro-ecosystems.

	Location/Agro-ecosystem/ Management combinations								
Location	FC	FC	FC	US	US	US	US	US	US
Agro-ecosystem	SUB	SUB	ORG	CNV	CNV	CNV	CNV	ORG	ORG
Crop rotation	2-yr	3-yr	3-yr	2-yr	2-yr	4-yr	4-yr	2-yr	4-yr
Tillage	MB	MT	MB	MB	MB	ST	ST	MB	MB
Crop residue	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes
No (in Figure 1)	1	2	3	4	5	6	7	8	9
Scenario	Rotation yield, Mg ha^{-1} yr^{-1}								
B	1.5bE†	2.3bD	2.1cD	6.0cA	5.2bB	5.0bB	4.2bC	4.0bC	4.5bC
S1	1.1cE	2.6aD	2.7bD	6.6bA	6.5aA	5.7aB	5.8aB	4.8aC	5.7aB
S2	1.9aF	2.8aE	3.2aD	7.2aA	6.8aA	5.9aB	6.1aB	5.2aC	5.9aB
	Temporal variance of rotation yield, [Mg ha^{-1}]^2								
B	2.5bE	2.9bE	2.1bE	8.5bB	9.8bA	7.6aC	9.4aA	7.7aC	6.5aD
S1	2.1bD	3.6aD	2.7bD	9.2aB	10.4aA	8.2aB	9.8aA	8.0aB	6.8aC
S2	3.5aE	3.8aE	3.2aE	9.7aB	11.3aA	8.4aC	10.7aA	8.4aC	7.1aD
	Coefficient of variation (CV) of rotation yield (%)								
B	32bA	25bB	22bB	24bB	29bA	19bB	22bB	29aA	32bA
S1	42aA	33aB	26bC	27bC	35aB	25aC	26bC	32aB	34bB
S2	49aA	32aC	40aB	32aC	37aB	27aC	33aC	32aC	39aB
	Conditional probability of simulated yield not exceeding CYT								
B	53	32	35	15	15	10	14	24	20
S1	60-75	47-62	46-59	28-44	40-52	29-45	32-51	30-42	28-36
S2	58-70	42-58	45-52	25-34	38-43	15-39	20-42	27-34	23-29

†, Baseline and simulated means, variances or CVs (columns) followed by the same lower-case letter do not differ significantly (p=0.05). Baseline or simulated means, variances or CVs (rows) followed by the same upper-case letter do not differ significantly (p=0.05).

Both measures of variation, (i.e., TV and CV), indicated that crop yields will be more variable in the future as compared with the baseline, the variation in TV is not expected to parallel the variation in CV across AESs, and small differences are expected between S1 and S2 as a result of CO_2 fertilization, especially in the FC. A relatively stronger buffering capacity (i.e., smaller TV and CV) is expected when crop residue of diverse crop rotations is incorporated into soil; however, it will be conditioned by AES and tillage option.

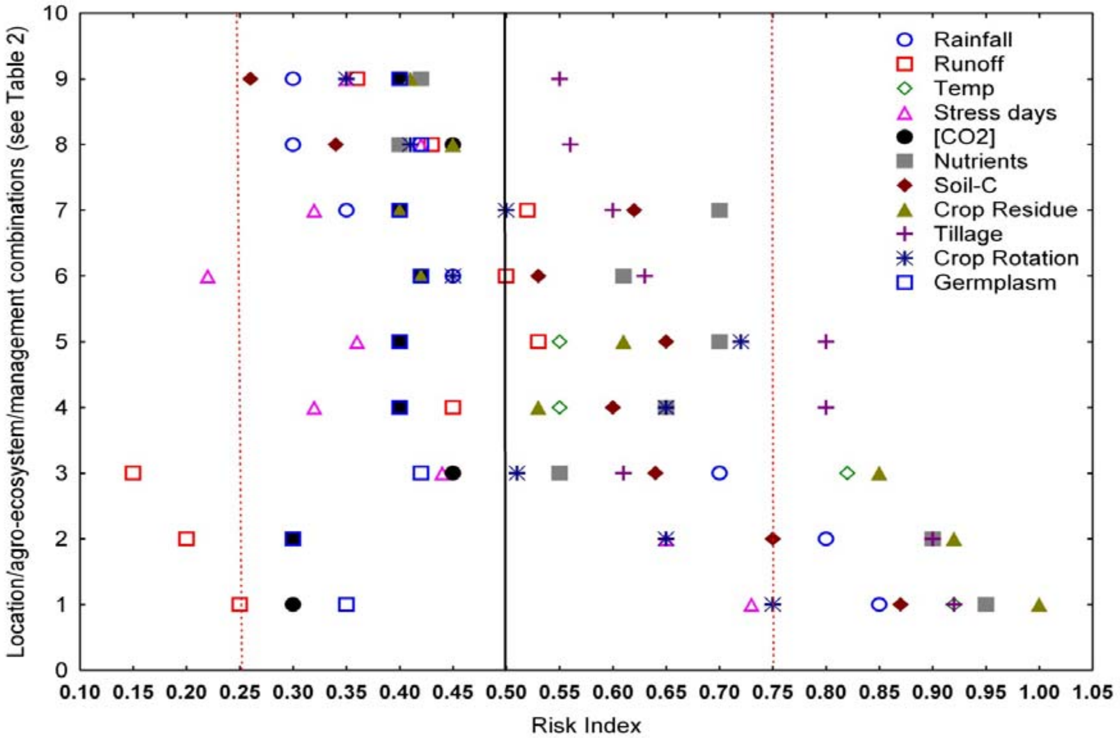
2.2. Conditional probabilities

Agro-ecosystems differed as to their CYTs as a result of different baseline and simulated TY, TV, and CV in relation to their projected NPP. Cumulative observed probabilities of exceeding mean TY or TV, but not CV, were always smaller in CNVs than ORGs or SUBs when compared with their respective cumulative expected probabilities (data not presented), consequently, the probability of simulated TYs exceeding CYTs in each AES was larger in CNVs and ORGs than in SUBs. Conditional probabilities of not exceeding CYT were much larger for the FC baseline (32-53%) as compared with those of CNVs or ORGs in the U.S. (10-24%). Also, the ranges of these conditional probabilities under simulated scenarios were larger in the FC, especially under traditional SUB management (58-70%), as compared with the largest range (38-43%) of the CNV in the U.S. Smaller conditional probabilities of not exceeding CYT is expected as a result of CO_2 fertilization; however, it is projected that all AESs in the FC and a few in the US will not be sustainable with CYTs exceeding 50%.

2.3. Risk indices of biophysical constraints

The risk indices (RI; Fig. 1), reflecting the probable impact (0 to 1) of a specific biophysical constraint on the outcome of AESs were small for [CO_2] (0.3) in SUB-FC to large (1.0) for crop residue under the traditional SUB crop rotation of wheat-fallow; however, the majority were >0.25 RI < 0.75. All biophysical constraints had variable impacts on the expected functioning of AESs and, consequently, on their sustainability.

Figure 1. Biophysical constraints and their risk indices for nine location/agro-ecosystem /management combinations under the S2 climate change scenario.



The impact of rainfall, temperature, soil-C, and nutrients, are expected to be stronger (RI>0.75) on AESs of the FC; whereas, tillage, residue management and, to some extent, [CO_2], are expected to have stronger impacts than other biophysical constraints (RI>0.50) on the probable outcome of CNVs and ORGs in the U.S. Improved germplasm was the only factor with a strong probable impact in all AESs, especially when other inputs are not limiting. In general, the feedback between TY and soil-C, particularly in SUBs and ORGs, is projected to be an important determinant of AES' sustainability through its buffering capacity against drought; whereas, nutrient run-off, reduced or lack of nutrient recycling as a result of crop residue removal, and excessive loss of carbon through CO_2 emissions, will adversely and increasingly impact sustainability and ecological compatibility of CNVs.

Simulation results suggested that the amount and timing of rainfall, temperature, soil-C, and nutrients are likely to limit productivity and highly likely to impact future sustainability in the FC as a result of climate change. The more diverse crop rotations, regardless of input levels, were more productive and their baseline and simulated yields were less variable than traditional, short-term rotations, especially when germplasm responsive to external inputs and nitrogen-fixing legumes were used, and when crop residues were incorporated into the soil. Negligible nutrient loss is expected in SUBs due to limited soil moisture; however, soil loss due to erosion was identified as a major factor impacting sustainability. The total potential nutrient loss to the environment is expected to be significantly larger in CNVs compared to ORGs or SUBs, and nutrients are expected to be depleted over time in SUB- faster than in ORG-managed soils. The carbon budget of all AESs is largely related to the choice of crops and length and composition of the crop rotation, and is expected to be influenced by external inputs, tillage system and removal of crop residues. Carbon depletion is expected to be less when nitrogen-fixing legumes are included in more diverse crop rotations and when crop residues are incorporated into the soil.

3. DISCUSSION

Farmers always had to adapt to the vagaries of weather on different timescales. However, the combination of greater climate vulnerability and lower adaptive capacity may create critical, additional challenges, especially to farmers in developing countries, as they confront global warming, lower and more erratic rainfall, and declining soil fertility in the coming decades (Pala et al., 2000; Magdoff, 2007). Empirical and simulation data, as summarized by conditional probabilities of not exceeding CYT (Table 2) highlight the need for adaptation and mitigation strategies beyond those currently used by farmers in various agro-ecosystems. There may be some unreasonable assumptions associated with estimating CYTs (Twine and Kucharik, 2009). Climate-induced trends in NPP are complicated to analyze because of the complex and nonlinear interactions between climate components and management components of AESs. While management has played a dominant role in increasing crop yields, climate may have contributed 20-25% to the increased crop yields over recent decades (Twine and Kucharik, 2009). Moreover, farmers' adaptation options and adaptive capacity, market fluctuations, and agricultural technology levels including genetic adaptation, and plant breeding will all affect the level of CYTs (Liebman et al., 2008; Miller et al., 2008). Nevertheless, the biophysical characteristics (Fig. 1) proved to be critical determinants of the overall performance and sustainability of the production systems under baseline and most-likely climate change scenarios (Belcher et al., 2004).

The SUBs, in the FC (Thomas, 2008) and elsewhere in West Asia (Cayci et al., 2009; Kassam et al., 2009) are experiencing a number of interlocking stressors, other than climate change and climate variability; these include population increase and associated environmental degradation, regionalized and globalized markets, and protectionist agricultural policies. Farmers in the FC already adapt to climate change by changing their cropping patterns and rotations through earlier sowing, using shorter duration crops, and switching to crops that are more tolerant to abiotic stresses. These adaptations can have mitigating effects by sequestering carbon in the soil (Heng et al., 2007). A major concern is the predicted large negative impact of climate change on NPP throughout the Mediterranean region, including the FC. The capacity for CO_2 fertilization to provide increased future food production, and its impact on agro-ecosystem processes, need to be carefully assessed through further model development and sensitivity testing (Friend, 2010); however, intensification of SUBs will likely push beyond the capacity of the ecosystem, resulting in sever environmental degradation (Sadras and Roget, 2004; Magdoff, 2007).

The long-standing debate over the trajectory of extensive agricultural production in the NCB and NGP deserves a new look (Turinek et al., 2009). The question is whether the negative impacts of farming practices that are incompatible with the environment and climatic extreme conditions, as the main cause of soil erosion, can be minimized. Agriculture in the NCB and NGP is likely to benefit from climate change in the next 30-40 years (IPCC, 2007), and the recently observed temperature increases may be extending crop-growing seasons in these regions (Rosenzweig and Tubiello, 2007) but not in the FC (Hole, 2008; Thomas, 2008) due to expected changes in rainfall amounts and patterns. However, resistance to change in response to climate change will be greatest in NCB and NGP because of the enormous capital and marketing systems embedded in current production systems (Rozenzweig and Tubiello, 2007). This is reinforced by the commitment of mainstream science and technology to further growth in productivity. Nonetheless, the need for environmentally-friendly and regenerative agronomic systems is compelling (Sandhu et al., 2007; Miller eta l., 2008), and it is equally so in developing countries, where the high costs of importing fertilizers, pesticides, and machinery cause mining of nutrients across large areas and impoverishment of rural environments and economies (Kassam et al., 2009). Therefore, more reliance on intensive management of ecological relationships than on external inputs to maintain productivity and profitability, especially in NCB and NGP, is advocated (Liebman et al., 2008).

Adaptation strategies, based on simulation results and supported by empirical evidence, will vary with agricultural systems, location, and climate scenarios. Adaptations to predicted climate change, such as adjusting the timing of planting and harvesting operations, substituting cultivars, and if necessary, modifying cropping systems, may not be adequate in the long-term (Rosenzweig and Tubiello, 2007). Higher levels of adaptation, such as changing cropping systems and crop types altogether, may become necessary. Moreover, mitigation strategies (i.e., sequestering carbon in soils and reducing greenhouse gas emissions) are needed to complement adaptation strategies; however, sequestering carbon in soil, but not reducing greenhouse gas emissions, is ultimately finite (Lal, 2008). Finally, the development of germplasm adapted to climate change using advanced, traditional and participatory plant breeding methods is expected to contribute to adaptation and mitigation efforts in developed as well as developing countries (Ludwig and Asseng, 2006; Lou et al., 2007).

Decision makers need a global evaluation of the sustainability of farming systems in order to define policies that might shape future agro-ecosystems and guarantee an acceptable level of ecosystem services (Castoldi and Bechini, 2010). However, emerging crop markets could determine which crops can be substituted under future climate change. Although the predominant crop rotation and management practices in the FC are changing in response to market forces, any further changes will be dictated by climate change (Hole, 2008). Similarly, the predominant crop rotation and management practices in the NCB and NGPs have been maintained for many years; however, a substantial decrease in corn yield due to climate change will justify adoption of more diverse crop rotations and less external inputs. Consequently, new crops may enter the U.S. and international markets (Li et al., 2009.). Future crop rotations will be controlled, to a large extent, by the ability to substitute current crops and by their future prices. A future change in relative prices could lead to vastly different rotations and areas of each crop grown, which would impact food production and other agro-ecosystem services (Sandhu et al., 2007; Kassam et al., 2009).

4. CONCLUSIONS

Climate change will disrupt many agro-ecosystem functions, altering their capacity to provide goods and services and rendering them more susceptible to degradation. Many agro-ecosystems will be less sustainable with a decreased capacity to respond or adapt to climate change, unless appropriate mitigation and adaptation strategies are implemented. The dominance of wheat in subsistence agro-ecosystems in the Fertile Crescent of West Asia, and corn and soybean in the conventional agro-ecosystems of the northern Corn Belt of the U.S., indicate that these agro-ecosystems, unlike organic agro-ecosystems, have inherently low levels of landscape diversity. The subsistence agro-ecosystems lack technological change, rely on low external inputs, and are increasingly marginalized; whereas, conventional agro-ecosystems of the northern Corn Belt focus on a single ecosystem service, over-consume environmental resources and release chemicals to the environment. Organic agro-ecosystems, on the other hand, focus on multiple ecosystem services, consume less environmental resources and retain more nutrients. Adaptations to future changes in climate variability and extremes may require an attention to stability and resilience of production, rather than to improving its absolute levels. Two measures of agro-ecosystem yield variation (i.e., temporal variance and coefficient of variation) may be used as measures of system stability or responsiveness, providing insights into superior cropping systems at a given agricultural zone. Additional dimensions to adaptation, related to social and cultural aspects that might either favor or hinder adoption of new technologies, depending on community dynamics and agro-ecosystem characteristics, are to be considered. Furthermore, it is important to consider the fate of any additional future production, and how much of it will contribute to food, feed, fiber and fuel production and to other ecosystem services.

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